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The 1951 Oyster Stock in the Rivers Crouch and Roach, Essex

and the influence of water currents and scour on its distribution: with an account of comparative dredging experiments

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CONTENTS

	page
INTRODUCTION	1
I THE STOCK SURVEY	3
1. The principal features of the survey area	3
2. The development of a sampling technique	3
3. The calibration of the survey dredge	5
4. The pattern of sampling	6
5. The calculation of oyster stocks	6
II THE INFLUENCE OF WATER CURRENTS AND SCOUR ON THE DISTRIBUTION OF OYSTERS IN BOTH RIVERS	9
1. The general distribution of oysters	9
2. The heavy spatfall in eddies	10
3. Current speed and differential spatfall on cross-river transects	15
4. Experimental work on scour	16
III COMPARATIVE DREDGING EXPERIMENTS	21
1. Oyster dredging on Shop Laying	21
2. *Crepidula* dredging on Southward Laying	21
3. Output of oysters per man-hour on Shop Laying and Paglesham Reach	23
4. Discussion	25
ACKNOWLEDGEMENTS	26
SUMMARY	26
REFERENCES	27

The 1951 Oyster Stock in the Rivers Crouch and Roach, Essex, and the influence of water currents and scour on its distribution : with an account of comparative dredging experiments.

INTRODUCTION

THE Essex oyster fishery has undergone a considerable decline since the beginning of this century. Lack of cultivation during the 1914-18 war together with heavy mortalities in 1920 (Orton, 1924) rendered once profitable oyster beds unproductive. The depredations of pests such as the slipper limpet (*Crepidula fornicata*) and the American whelk tingle (*Urosalpinx cinerea*) increased as a result of this lapse, and further intensified as labour was attracted away into more remunerative channels. Depreciation of stocks, coupled with successive spat failures, brought the industry to a low level of activity by the end of the recent World War.

The Ministry of Agriculture, Fisheries and Food started research at Burnham-on-Crouch in 1947 with the aim of helping the industry regain its former prosperity. As a first step, some derelict oyster layings in the Rivers Crouch and Roach were leased or purchased and restocked; they were cultivated by the Ministry's research smacks, when not required for other duties.

A scientific programme was planned, to further the gradual extension of cultivation and increase in stocks, as well as to widen our knowledge of the general biology of the oyster. Already the studies of Knight-Jones (1952), on the reproduction of oysters in the area during 1947, 1948 and 1949, have led to a greater understanding of the environmental complexities of these two rivers and the way they affect spawning, liberation, distribution and settlement of the larvae. The work of Mistakidis (1951) on the composition of the bottom fauna in both rivers, links closely with the problem of oyster spat settlement, and is of immediate practical value. The life histories, abundance and distribution of the principal pests are being studied with a view to introducing adequate measures of control (Waugh et al. 1952; Hancock, 1955; Cole and Hancock, 1955). Attention has been given to the development of power-operated dredges of orthodox and new design, both for use on existing oyster layings, and on derelict ground to be reclaimed. In addition, valuable information is constantly accumulating on hydrographic conditions within the river system.

As time goes on, so the stocks of oysters and the conditions for their settlement, growth and survival, can be expected to improve. Larval abundance in the area during the spawning season has shown a steady improvement since 1947 (Knight-Jones, 1952; Waugh, 1951, 52) as a result of the restocking programme, but recent spatfall failures and winter mortalities have offset the advantage of this gain.

To assess the rate of improvement of stocks and the value of measures taken from year to year in the programme of rehabilitation, it is necessary to undertake periodic surveys of the oyster population in both rivers. Although a tally is kept of stocks on the Ministry's layings, little was known of the abundance and the age of oysters on privately owned layings, and over the considerable expanse of uncultivated ground in the fishery.

In the autumn of 1951, a preliminary stock survey was made, the results of which form the first part of this paper. Also included, is a description of experimental work designed to clarify the picture of oyster distribution arising from the survey, and an account of efficiency tests on various types of dredges.

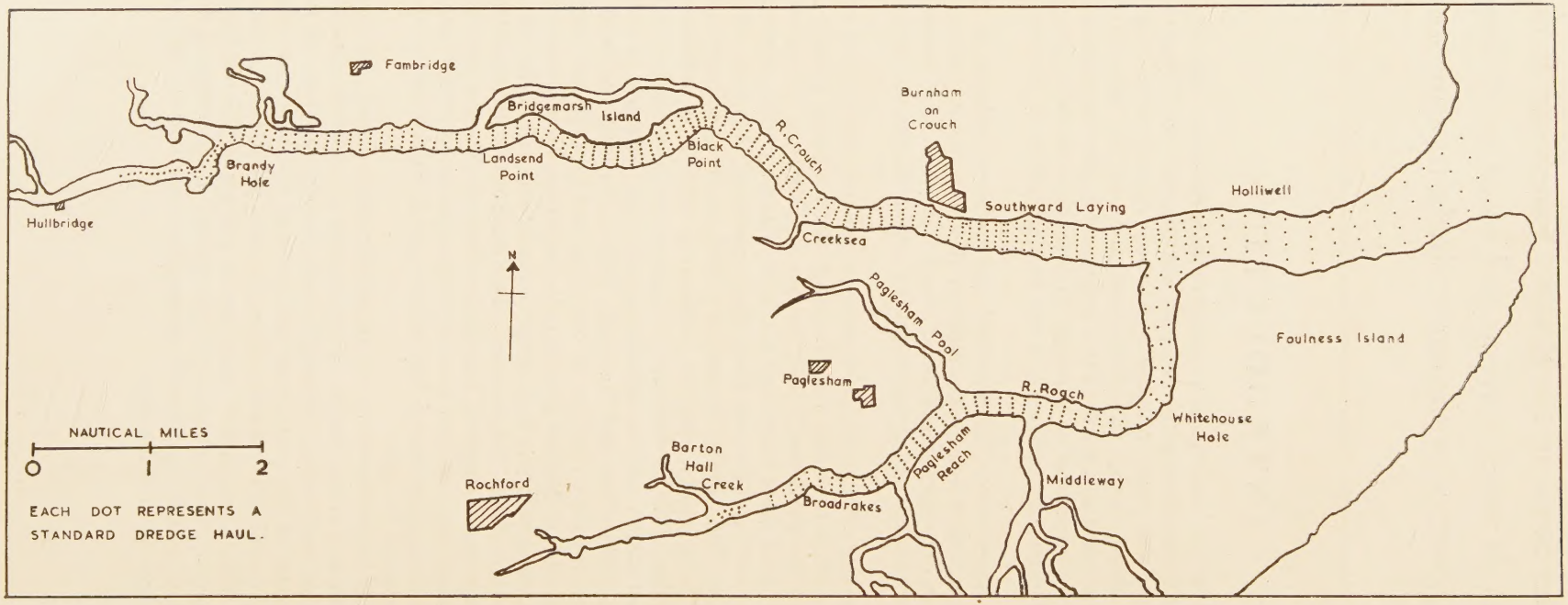


Fig. 1. *The sampling pattern in the rivers Crouch and Roach.*

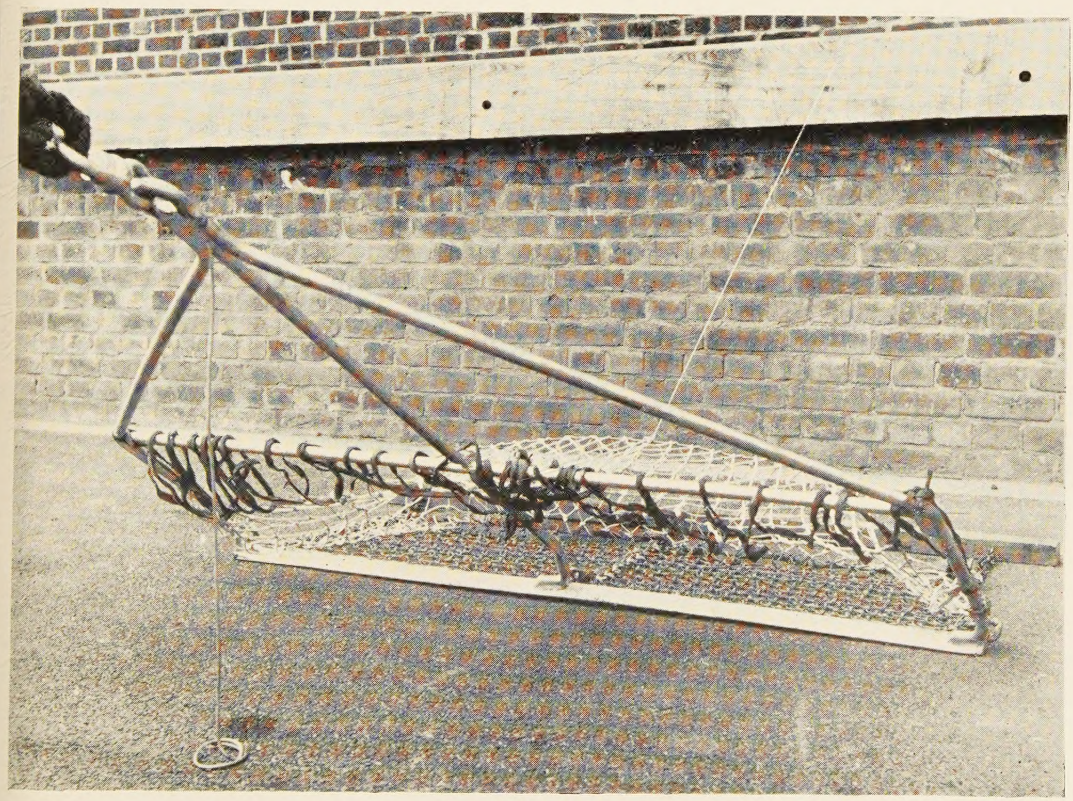


Plate 1. (*top*) *The hand dredge.* (*bottom*) *The winch-operated power dredge.*

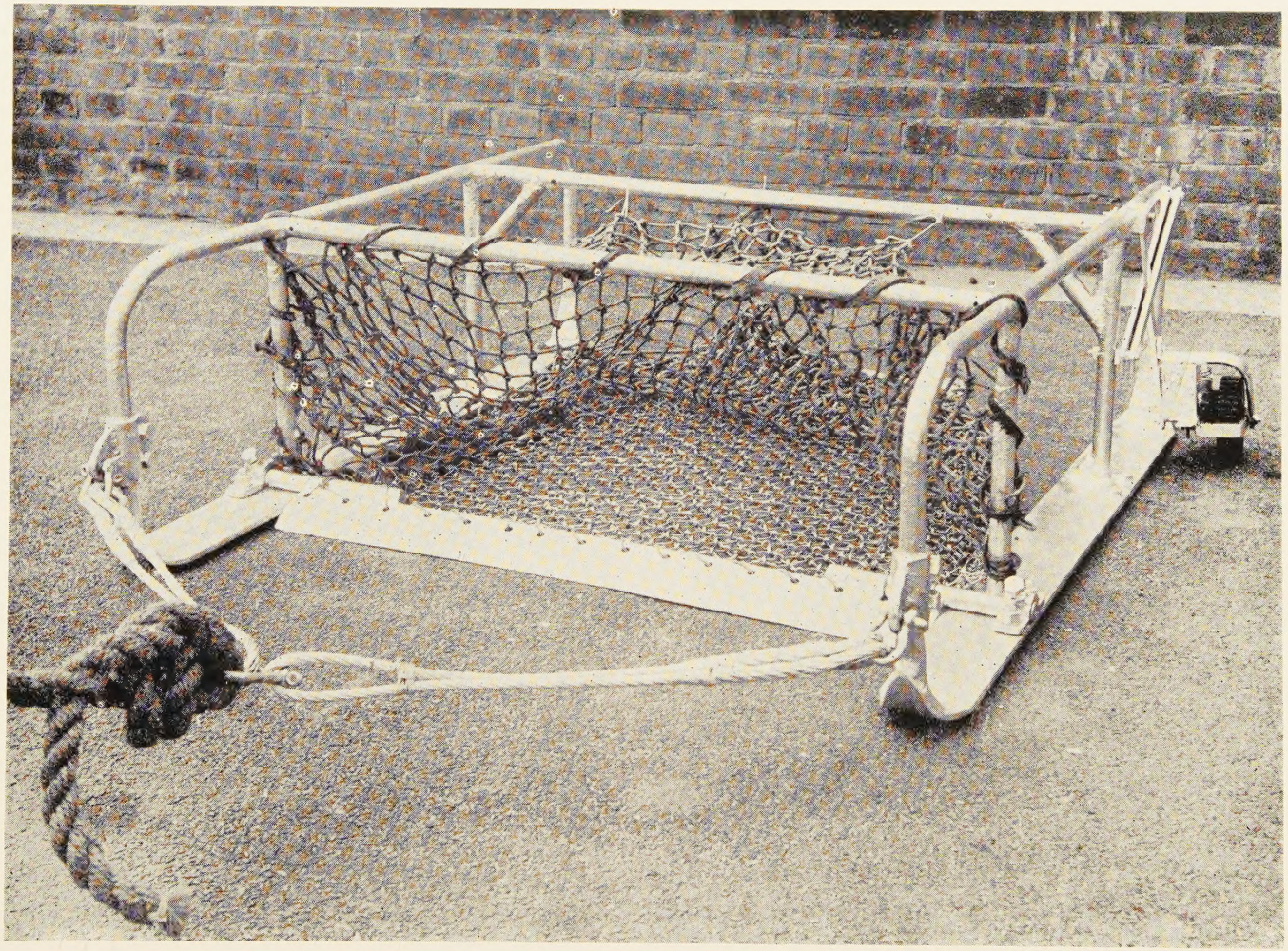


Plate 2. *The survey dredge.*

PART I. THE STOCK SURVEY

1. The Principal Features of the Survey Area

The sampling area extended from the mouth of the R. Crouch to Hullbridge in its upper reaches, a distance of 14 miles, and from the confluence of the R. Roach with the Crouch to Barton Hall Creek, 6 miles up river (Fig. 1). Hullbridge and Barton Hall Creek represent the upper limits of oyster distribution in the rivers Crouch and Roach respectively. Certain important creeks were omitted from the survey. The total area of river bed below L.W.M.O.T. coming within the scope of this work was about 13½ million sq. yd. This figure, calculated from a 6 inches to 1 mile O.S. map, did not allow for the transect curvature of the river bed, which is of a low order.

No detailed information was at hand concerning the distribution of oysters on other than the Ministry's layings, although the positions of privately owned beds were known. Permission was sought, and usually granted, to work on these layings and in the uncultivated reaches of the river. As a general rule, oysters are confined to that part of the river lying below L.W.M.O.T., but it is not unusual to find scattered individuals above this mark, particularly where the bank or sea wall is steep and rocky. Strong wave action during stormy weather may carry oysters from the inshore margins of sub-littoral oyster layings up into the intertidal zone.

The river beds are for the most part composed of mud stiffened in varying degrees by the shells of living and dead molluscs, with occasional outcrops of hard clay, sand and gravel. The cleanest bottoms are usually in the regions of greatest tidal scour (e.g. in the Fairway off Burnham), and where intensive oyster cultivation is still practised.

Both rivers are tidal, with a vertical range of between 3 and 6 metres. The velocity of the current varies in time and place, reaching a surface speed greater than 1 metre per second over the deeper channels at the period of maximum flow during spring tides.

2. The Development of a Sampling Technique

Because of the magnitude of the area to be surveyed and the patchiness of the oyster population within its boundaries, a sufficiently high number of quantitative hauls had to be made, each haul sampling a large enough area of the river bottom. Furthermore, the survey had to be started as soon as possible after the summer spawning season, before the work of lifting oysters for sale got under way, and was to be completed within 4-6 weeks, so as not to interfere with the routine programme of oyster cultivation. Thus speed, coverage and quantitative accuracy were the salient features of any proposed sampling technique.

Three sampling instruments were available; the Petersen grab, a winch-operated oyster dredge used for the cultivation of the Ministry's grounds, and the standard hand dredge used by Essex oystermen (Plate 1). The Petersen grab, though a well-tried quantitative instrument, had a coverage of only 0.1 sq. metres, insufficient for the task in hand. It cannot be used with accuracy in a swift tidal current or from a moving vessel, thus restricting its use to a short period before and after high and low slack water. The winch-operated oyster dredge gave adequate coverage per haul and could be handled with ease and speed at all states of the tide. Its dredging efficiency, however, was unknown; in April 1951 the following experiment was made to test its catching power, over a known population of slipper limpets.

An area of clean, soft and gently sloping mud, 50 yd. × 50 yd., at the confluence of the Roach and Crouch, was marked out with four long poles, or beacons, at low slack water. As the tide rose, a further eight beacons were planted from a small boat; four on two parallel sides of the area, adjacent beacons being 10 yd. apart. Thus the ground was divided into five lanes, A-E, each lane being 50 yd. × 10 yd. in extent. 10,000 *Crepidula* chains were scattered as evenly as possible over the whole area at high water, giving an average density of four chains per sq. yd. One tow per lane was now made by the oyster smack, dragging two winch-operated dredges, each having a blade 4 ft. 6 in. wide. The dredges were shot 5 yd. before reaching a lane and hauled the same distance beyond. As a completely clear expanse of mud surrounded the area, only the known population of slipper

limpets was sampled. The number of limpet chains in each dredge was counted after each haul, and the proportion of the expected catch calculated (Table I).

Table 1: *Calibration of the winch-operated dredge*

Lane	*Dredge A*		*Dredge B*	
	No. Crepidula *chains caught*	*% of expected catch*	*No.* Crepidula *chains caught*	*% of expected catch*
A	138	46%	90	30%
B	36	12	Nil	Fouled
C	95	32	201	67
D	101	34	69	23
E	126	42	84	28
TOTALS	496	33%	444	30%

Under the conditions of the experiment, the winch-operated dredge had a fishing efficiency of about 31%, thought to be too low for survey purposes. The hand dredge was also rejected as a sampling instrument, being of the same design as the winch-operated dredge.

It is not likely that the efficiency of a dredge, as a sampling instrument, can ever approach that of the grab, yet it was thought possible and expedient to build a new type of dredge which would have a greater catching power per unit length of blade than the existing power dredge, and still retain a fair degree of mobility. To this end the survey dredge was constructed (Plate 2). It consisted of two skids of $\frac{3}{8}$ in. steel strip, each 4 ft long and 4 in. wide. Each skid supported a simple vertical framework of 1 in. diameter iron bar rising to a height of 1 ft. 3 in. from the ground. A sharpened blade or 'scythe' separated the skids at ground level. This blade was furnished with a cylindrical boss welded on at either end, which fitted into sockets bolted on to the upper surface of each skid. Two horizontal lengths of 1 in. diameter iron piping held the skids apart at the upper level of the skid framework, one towards the front and the other towards the back of the dredge. The front tube was aligned with the after edge of the blade and the forward uprights of each skid frame, to form a rigid opening to the mouth of the net or 'bag'. The points of attachment of the towing bridle to the dredge frame were adjustable. The bag was 4 ft long from mouth to 'cod end', being made up of $1\frac{1}{2}$ in. mesh wire rigging on its lower surface continuous with thick twine netting of the same mesh size on its upper surface. The mouth opening of the bag was secured by rawhide strips to the structures already described, while the 'cod end' was closed by two strips of canvas sewn to the meshes and laced together. All ferrous components of the dredge were galvanised. A pedometer was fashioned from $4\frac{1}{2}$ in. diameter phosphor-bronze gear wheel blocked in with oak, fitted with a revolution counter. In practice, the pedometer was trailed along the ground at a point towards the rear end of the dredge, by means of a length of brass strip attached to the main framework. Preliminary experiments showed that the pedometer worked fairly well on all types of ground, the principal trouble arising when small shell fragments became jammed between the cogs operating the counter.

Trials were made to determine the most satisfactory point of bridle attachment, and angle of attack of the dredge blade. When in use, the short bridle of the fully rigged dredge was connected to the winch by means of a coir rope passing over a pulley fixed to a gantry in the stern of the oyster smack. The length of rope required for satisfactory towing was dependent on the state of the tide. On reaching the end of a station, the dredge and catch were hauled as quickly as possible to the surface, and maintained there for a short while to wash away mud and gravel. The dredge was then lifted out of the water, the bag swung

inboard and the catch emptied on deck by unlacing the cod end. The pedometer reading was taken and the cod end relaced for the next haul.

In principle, the dredge acted as a plane, skimming off a thin surface layer as it travelled sled-like over the ground. Its weight, 120 lb. in air, helped to counteract the towing lift, which was kept down by using a sufficiently long towing rope. The skids were wide enough to prevent the dredge sinking into soft ground and filling up with surface mud. The 'bite' of the blade was dependent on the extent and angle of that portion projecting below the skids. The area covered by the dredge in any particular haul was easily ascertained from the distance travelled, the blade being exactly 1 yd. wide. A maximum tow of 25 yd. per station was judged sufficient; longer tows were less quantitative, due to the premature filling of the bag with bottom fauna and debris.

3. The Calibration of the Survey Dredge

It was not convenient to repeat the earlier method of dredge calibration over a planted population of *Crepidula*. Instead, the oyster populations on two short stretches of river bottom in the Crouch were calculated from intensive Petersen grab surveys, and the new dredge calibrated against these populations. On Creeksea Laving, a short distance upstream from Burnham, the bottom is cultivated to some extent, is firm and fairly clean, and bears relaid oysters at an average density of 15 per sq. yd. In contrast, the bottom off the mouth of Bridgemarsh Creek is soft and well covered with cultch. This area, though not cultivated, is very favourable for spat settlement, and supported an extensive population of young oysters at an average density of 25 per sq. yd.

Well below low water mark in each locality, an area 50 yd. by 25 yd. was marked with buoys, and each area again sub-divided into five lanes, 10 yd. by 25 yd. Ten grab hauls per lane, giving a total of fifty for each ground, were made with the Petersen grab during the period of least tidal flow on two consecutive days. Oysters of all age groups from each catch were sorted, counted and returned to the ground. The mean density of oysters in each area was calculated from the results, assuming the Petersen grab to be 100% efficient.

Ten hauls per area were made with the survey dredge, one in each lane. The oyster total per haul was corrected for exact distance travelled over the ground. The mean density of oysters on the two areas, according to the survey dredge, was then calculated and the results compared with those of the Petersen grab. From Table 2 it will be seen that the

Table 2: *Calibration of the survey dredge against the Petersen grab*

	Hard ground		*Soft ground*	
	Petersen grab	*Survey dredge*	*Petersen grab*	*Survey dredge*
Number of hauls	51	10	50	9
Total area sampled (sq. yd.) . .	6·0096	238·40	5·980	137·1
Total number of oysters caught .	94	1156	153	2970
Mean density oysters per sq. yd. .	15·41	6·53	25·58	21·66
Assumed efficiency of grab . .	100%		100%	
Calculated efficiency of dredge . .		42·4%		84·7%

efficiency of the survey dredge varies widely according to the nature of the bottom, and the abundance of fauna and debris thereon. On the whole, the oyster-bearing parts of the river beds lie between the two selected extremes of hardness. The results for both areas were amalgamated, in order to arrive at a reasonable working estimate of dredge efficiency. This estimate, approximately 60%, is supported by the results of later comparative dredging

experiments (Table 6), which show that the survey dredge has almost twice the catching power of the winch-operated dredge already seen to be about 31% efficient (Table 1).

4. The Pattern of Sampling

By the end of August 1951, the survey dredge had been built and its trials completed. A start was then made on the survey. In the wider parts of the rivers, short hauls were made at about 50 yd. intervals on cross-river transects 200 yd. apart (Fig. 2), though it was found expedient to vary this pattern in barren and well-stocked areas. The inshore hauls were sited at L.W.M.O.T. No special steps were taken to mark this line, so that at times other than low slack water, its position was found by reference to the O.S. map, and the long experience of the skipper of our research smack.

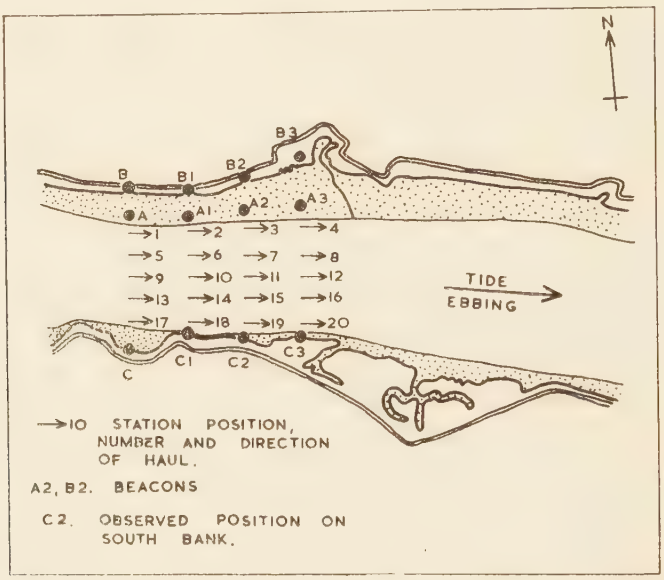


Fig. 2. *Section of the River Crouch, showing arrangement of survey stations.*

The transects were fixed by placing a conspicuous marking beacon A in the mud or on the sea wall at a known position from the O.S. map, and then planting beacon B some distance behind A, so that A and B were in line with an observed and known position C on the opposite bank. It was found convenient to work three or four transects at a time. The vessel was allowed to drift on to a station with the tide, and as beacon A came into line with beacon B, so the dredge was lowered. The engine was used to a greater or lesser extent depending on the speed of the tide, to maintain ship's headway, but the towing speed of the dredge over the ground seldom exceeded $1\frac{1}{2}$ knots. If the tidal flow was not too great, it was possible to sort out the catch and reset the dredge whilst the vessel drifted slowly on to the next transect station.

The oyster catch was separated into five year groups, size and thickness being used as criteria. General notes were made after each haul, on the abundance of *Crepidula*, the quantity of cultch and the nature of the bottom.

In this way, a total of 700 stations were covered in 31 working days (Fig. 1). As the area under survey extended over $13\frac{1}{2}$ million sq. yd., the mean order of sampling was 1 in 760 sq. yd.

5. The Calculation of Oyster Stocks

The oyster catch at each station was adjusted for distance travelled and for dredge efficiency. The final calculation gave an estimate of the numbers of 1, 2, 3, 4 and over 4 year-old

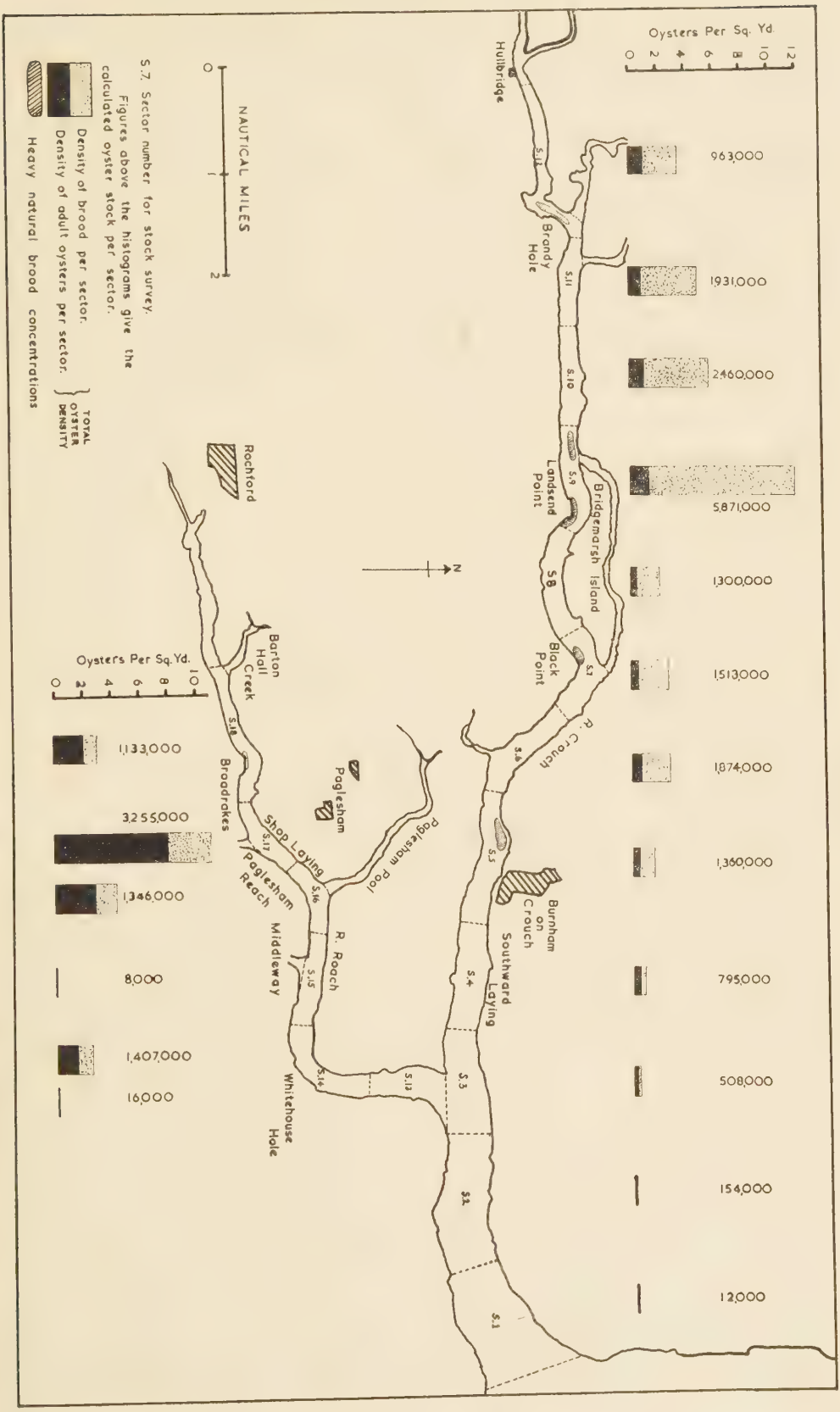


Fig. 3. *The general distribution of* Ostrea edulis *in the rivers Crouch and Roach, October,* 1951.

native oysters, as well as Portuguese oysters, for a standard 25 yd. haul, using a hypothetical dredge of 100% efficiency. To estimate the total stock in the area, both rivers were divided into arbitrary sectors (Fig. 3); twelve in the Crouch and six in the Roach. The boundaries of these sectors were laid down, as far as possible, in accordance with observed differences in stock density, and from the point of view of ease in assembling data. Such a scheme was also judged to be of value in the interpretation of the routine oyster larvae samples, taken in different parts of the two rivers during the summer spawning season. The sectors varied in extent; their areas were calculated by using a polar planimeter in conjunction with a 6 inches to 1 mile O.S. map, the inshore margin of each sector being taken as L.W.M.O.T.

In estimating the total oyster population and its age composition for any particular sector, the year group totals for all stations in that sector were added together, and these grand totals divided by the area covered during dredging, to give an average age group density per unit area of ground. These densities were then multiplied by the sector area.

The general distribution of oysters over the two rivers is given in Fig. 3, whilst more detailed information on age composition in the sectors is presented in Table 3.

Table 3: *The age composition of the oyster stock in all sectors of the rivers Crouch and Roach*

River Crouch

Sector number	*Area of sector in sq. yd.*	*No. of sampling stations*	*Total area sampled in sq. yd.*	*Mean density of oysters per sq. yd.*	*Calculated nos. of oysters per sector (in thousands)*						
					1 yr.	*2 yr.*	*3 yr.*	*4 yr.*	*> 4 yr.*	*Portuguese*	*Total*
1	2,320,300	24	600	0·0051	–	–	12	–	–	–	12
2	2,016,300	28	700	0·0764	114	40	–	–	–	–	154
3	1,192,600	60	1,500	0·4264	289	139	57	17	6	–	508
4	945,700	63	1,575	0·8412	376	224	126	44	19	6	795
5	856,700	57	1,425	1·5878	979	234	80	40	25	2	1,360
6	674,700	50	1,250	2·7785	1,420	259	119	45	30	1	1,874
7	574,000	50	1,250	2·6362	1,202	175	85	25	9	17	1,513
8	629,200	54	1,350	2·0665	1,053	162	70	12	3	–	1,300
9	499,500	46	1,150	11·7542	5,187	481	152	35	13	3	5,871
10	428,800	34	850	5·7371	2,025	308	89	29	4	5	2,460
11	392,000	32	800	4·9266	1,615	159	101	40	11	5	1,931
12	272,000	34	850	3·5433	678	178	73	28	1	5	963
Total	10,801,800	532	13,300	1·7350	14,938	2,359	964	315	121	44	18,741

River Roach

13	617,600	18	450	0·0259	–	2	12	2	–	–	16
14	556,600	23	575	2·5283	600	479	223	69	34	2	1,407
15	436,600	31	775	0·0199	1	3	4	–	1	–	9
16	307,800	28	700	4·3755	470	607	171	55	33	11	1,347
17	291,400	31	775	11·1717	940	1,148	676	285	197	9	3,255
18	345,600	37	925	3·2797	391	421	181	80	56	4	1,133
Total	2,555,600	168	4,200	2·8044	2,402	2,660	1,267	491	321	26	7,167

There appeared to be about 18½ million native oysters in the Crouch at the time of the survey, 15 million of which were one-year-old brood oysters, the remaining 3½ million being spawning stock. Sectors 8, 9, 10 and 11, lying between Brandy Hole, in the west, and Landsend Point, in the east, contained the greatest stocks of oysters, with the peak of brood abundance in sector 9, between Landsend Point and the mouth of Bridgemarsh

Creek. In addition to these natural spatting grounds, this stretch of the river includes two cultivated layings occupied by the Ministry, and two other private layings. The density of oysters fell off considerably between Creeksea and the mouth of the Crouch, the only concentrations occurring at a point on the north bank just west of Burnham, on Southward Laying and at Holliwell.

Of the $7\frac{1}{4}$ million oysters in the Roach, only $2\frac{1}{2}$ million were one-year-old brood, the remaining $4\frac{3}{4}$ million being spawning stock. This contrasts with the situation in the Crouch, where the brood stock far outnumbered the adult population. Furthermore, there were at least one million more adult oysters in the Roach than in the Crouch.

About 80% of the Roach stocks were concentrated in the stretch of river lying between Paglesham Pool and Broadrakes Laying, a distance of just under two miles, with the peak density occurring in Paglesham Reach. The only other concentration of any significance was found to the east, lying in deep water at White House Hole. The Roach survey did not include Paglesham Pool and other creeks, where considerable quantities of fattening oysters were known to be laid, nor a small ground above Broadrakes Laying supporting a mixed population of native and Portuguese oysters.

PART II

THE INFLUENCE OF WATER CURRENTS AND SCOUR ON THE DISTRIBUTION OF OYSTERS IN BOTH RIVERS

1. The General Distribution of Oysters

A common feature of the oyster distribution in both rivers was the existence of peak populations in the middle reaches. Progressive deterioration of the river bottom is the limiting factor to distribution in the lower reaches of both rivers. Conditions for the settlement of spat are least satisfactory in these muddy stretches; from Southward Laying seaward in the Crouch and from the Middleway seaward in the Roach. The shallow waters of the upper reaches undergo the greatest daily and seasonal fluctuations in temperature and salinity; high, up-river mortalities of young and old oysters are a feature of severe winters. Between these lower and upper zones lie the most productive and profitable grounds.

The greater part of the oyster population of the Roach was situated between Paglesham Pool in the east and a point just beyond Broadrakes in the west, a stretch of highly cultivated ground some two miles in extent. Fig. 4 gives the relationship of adult to brood density as roughly 2:1, contrasting sharply with the situation in the Crouch, where the brood population was far in excess of the meagre adult stock. There is further evidence of a much higher 1950 spatfall in the Crouch than in the Roach. Mr. W. Roe, formerly of this laboratory, collected cultch at frequent stations in both rivers during the autumn of 1950, and counted the numbers of living and dead oyster spat on 20 roughly equal shells at each station. From his figures, I have calculated the average total spatfall per 20 shells for each stock survey sector, and have presented the results in Fig. 5. There is no doubt that the Crouch is a much better spatting river than the Roach, despite its smaller spawning stock.

The reasons for this difference in brood productivity are as follows: firstly, a much greater area of bottom is suitable for settlement in the Crouch than in the Roach. Secondly, it is certain that planktonic larvae of all ages pass from the Roach into the Crouch during the ebb tides. The set of the tide changes on the flood, and many of these larvae are carried up the Crouch. The Roach, therefore, contributes to the larval population, and, eventually, to the adult oyster population of the Crouch. Thirdly, the course of the Crouch is much less uniform than that of the Roach; five natural brood concentrations occur in the Crouch—

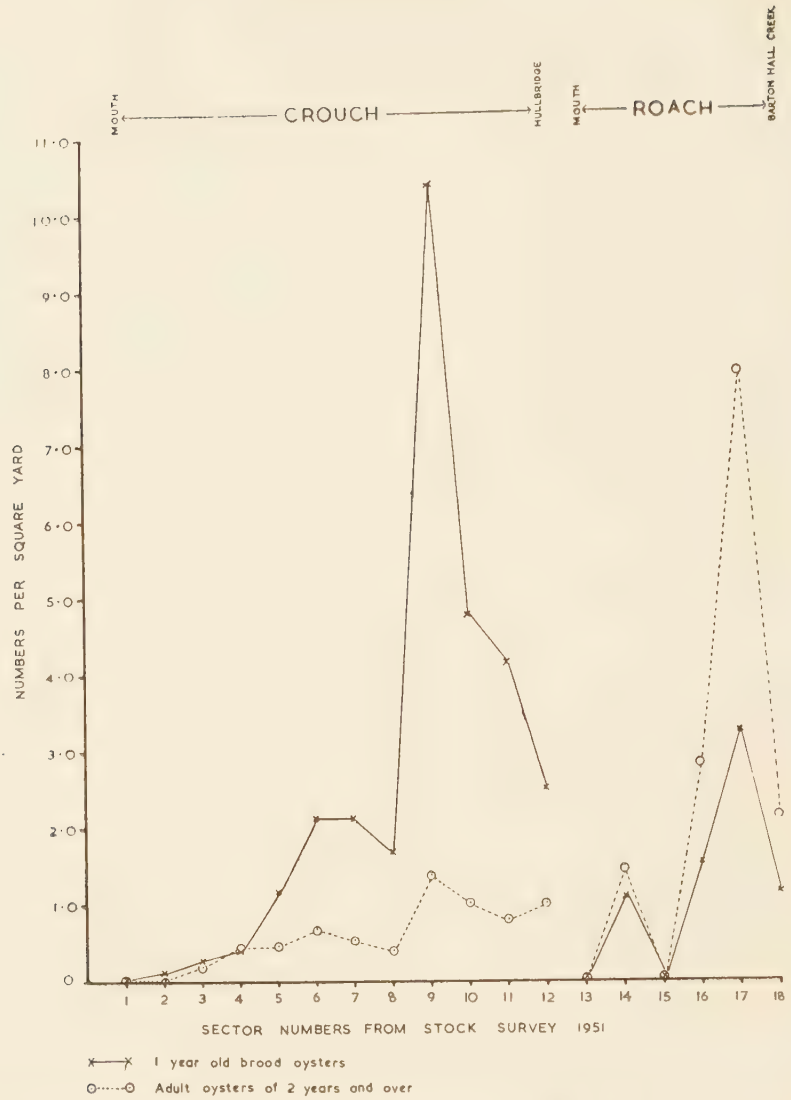


Fig. 4. *Brood and adult oyster densities in the rivers Crouch and Roach, October* 1951.

four under inshore eddies (Fig. 3)—and only one in the Roach. It appears, therefore, that the brood productivity of our rivers is related to topographical features; in particular, the way in which sudden changes of direction can interfere with tidal flow.

2. The Heavy Spatfall in Eddies

Extensive eddies occur in the Crouch at Brandy Hole, Landsend Point, Black Point and a position towards the north bank of the river, just west of Burnham. At Black Point and Landsend Point the steep sea wall deflects water flow at all states of the tide. As the ebb current increases in speed from high slack water, so an eddy spreads from the western extremity of each promontory. The eddy widens as the tide accelerates to its peak velocity, and takes on an oval appearance at the surface. The offshore turbulent margin extends some 30 yd. from the sea wall at spring tides. The water at the tip of the eddy revolves slowly in a clockwise direction; the speed of surface flow in the eddy and for some distance behind, is much slower than the flow outside (Fig. 6). As the ebb current loses speed after its early peak, and as the tidal level drops, so the volume of the water affected by the eddy system gradually diminishes. At low slack water the eddy disappears. On the following flood tide,

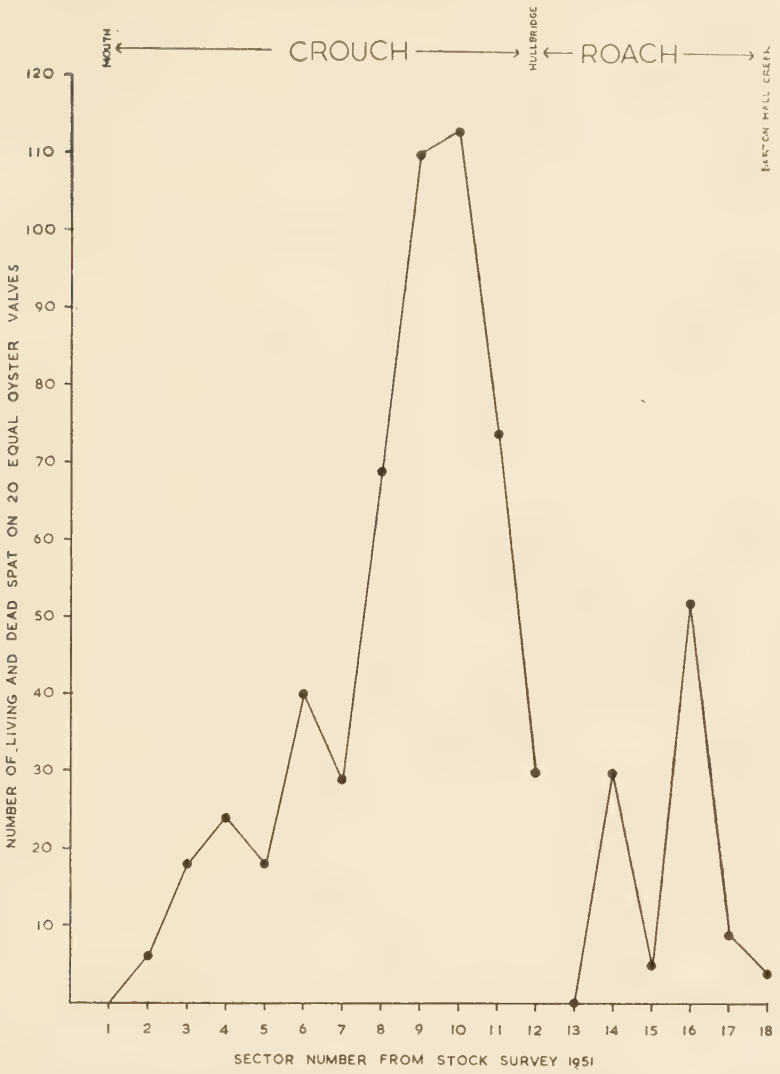


Fig. 5. 1950 *oyster spatfall in rivers Crouch and Roach (from data collected by W. D. Roe).*

eddies develop from the eastern extremities of the promontories, and are similar in nature to those formed on the ebb, except that there is an increase in volume until the tide slackens to high water again.

Several authors have already drawn attention to high oyster settlement under eddies; Kändler (1928) and Orton (1937) were of the opinion that planktonic larvae accumulate within the system during tidal flow, presumably as a result of the rotatory movement of the water. This theory is considered to be hydrodynamically unsound by many authorities, and an attempt was made to resolve this dispute during the oyster spawning seasons of 1952 and 1953.

100 litre samples of water, from a depth of one metre, were pumped through a fine mesh silk net, at stations inside and outside the flood and ebb eddies at Black Point and Landsend Point (Fig. 7). The oyster larvae from each sample were counted, and measured where necessary; the results are set out in Table 4. The sampling technique has been described by Knight-Jones (1952).

It is now possible to state that the physical forces at work in these eddies do not influence the concentration of purely planktonic oyster larvae, on either the ebb or the flood tide.

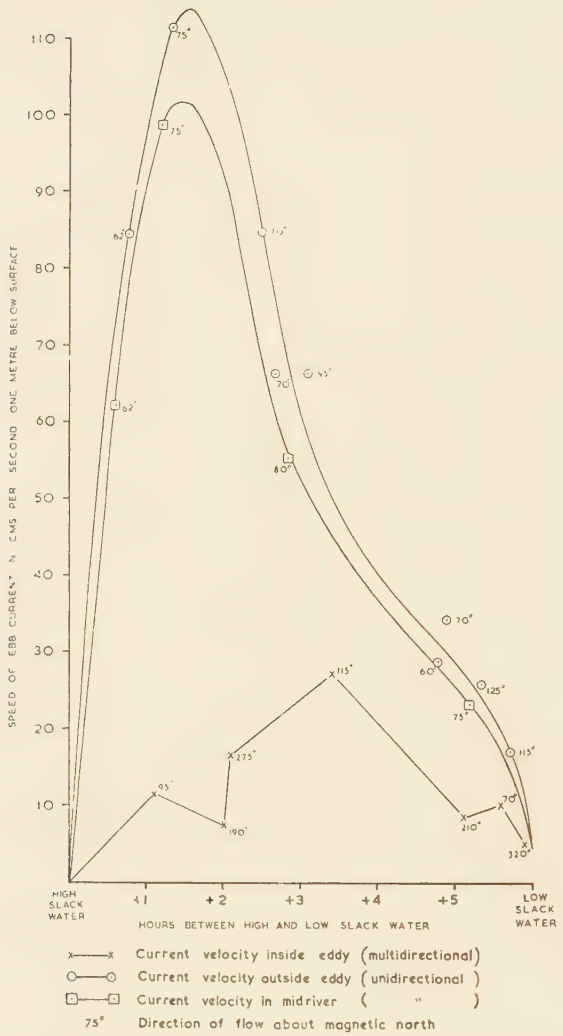
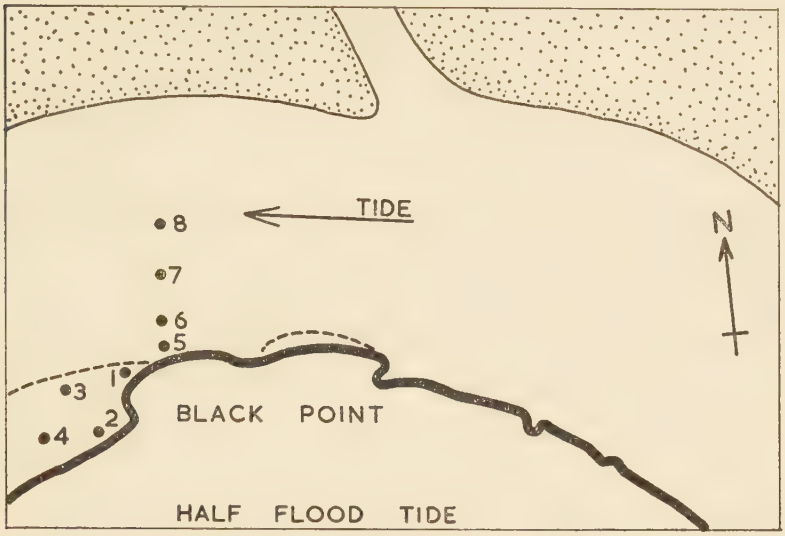


Fig. 6. *Ebb current velocity inside and outside eddy at Black Point, a.m.* 20 May 52.

A high larval count inside an eddy was a rare occurrence; even then, size measurements showed that it was the outcome of larval liberation by the oyster stock underneath, during the act of sampling. In short, the manifold differences in numbers inside and outside, that one might expect if the accumulation hypothesis were true, did not occur.

The evidence collected by Knight-Jones (1952), on the horizontal distribution of oyster larvae in the Crouch, suggests that they become widely dispersed from their point of origin during the planktonic phase. The degree of dispersion will depend on the time spent in the plankton, and on the manifold horizontal and vertical differences of flow in the river. One can visualise, therefore, a constant stream of dispersed eyed larvae about to settle, being brought under the influence of eddy systems during tidal pulsation. Korringa (1941) has already stressed the primary importance of current velocity on the horizontal distribution of the spatfall; in an inshore eddy, the current speed at the surface, and presumably also on the bottom, is considerably less than offshore, except where local and evanescent vortices arise. It seems reasonable to conclude therefore, that spat concentrations in eddies are the result of the reaction of eyed larvae to reduced current, rather than the purely physical effect of eddy forces on suspended organisms. An eddy acts as a trap for eyed larvae searching for good settling conditions, whilst the younger planktonic larvae are not affected.



The broken line represents the offshore margin of the eddy. The stations at Landsend Point followed a similar pattern.

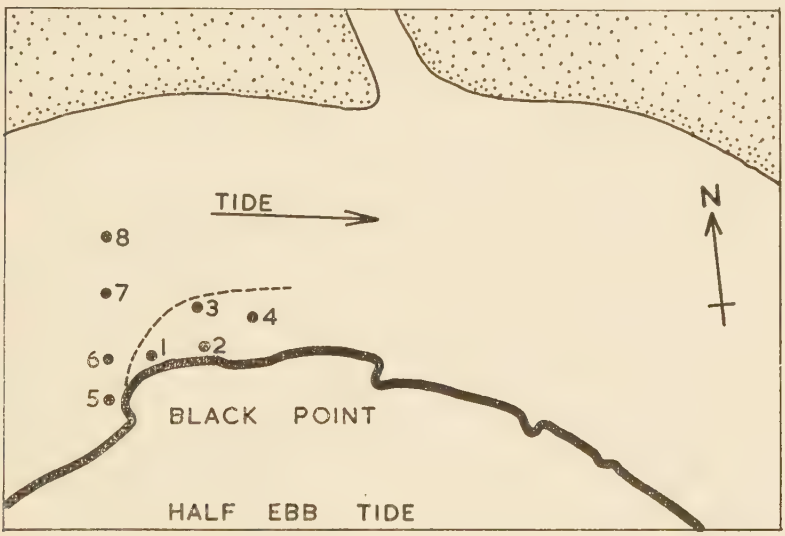


Fig. 7. *The arrangement of sampling stations inside and outside Black Point eddy.*

A proportion of all eyed larvae entering an eddy during a tidal cycle will be induced to settle; this proportion will depend on:

(a) The length of time during which the speed of flow at the bottom is retarded below the critical level for crawling and subsequent settlement. Flowmeter experiments suggest that the duration of this favourable period will be far greater inside, than outside, the eddy. There is, unfortunately, no direct experimental evidence on the critical level of flow, above which *O. edulis* cannot settle.

(b) The area of suitable settling surface within the margins of the eddy. Some slight water movement is necessary, to keep these surfaces free from silt.

(c) The intensity of the gregarious factor (Cole and Knight-Jones, 1949; Knight-Jones, 1951) arising from existing brood stocks and from newly settled spat.

Thus the solution to the problem appears to depend upon the behaviour of eyed larvae: in particular, their ability to suspend the act of settlement, within certain limits, until favourable conditions prevail.

Table 4: *Results of the sampling experiment inside and outside the eddies at Black Point and Landsend Point*

Location	*State of tide*	*Date*	*Nos. oyster larvae per 100 litre sample*							
			Stations inside eddy				*Stations outside eddy*			
			1	2	3	4	5	6	7	8
Black Point	Half flood	1 July 53	148	40	216	96	99	173	269	292
		2 July 53	70	90	42	31	63	62	299	304
		3 July 53	62	245	135	31	91	98	316	257
		6 July 53	70	42	42	29	16	72	63	105
		23 July 53	26	18	14	1	21	22	55	25
			376	435	449	188	290	427	1002	983
			Total larvae . . *1448*				Total larvae . . *2702*			
			Mean no./sample . *91*				Mean no./inshore sample (Stns. 5 and 6) *90*			
	Half ebb	1 July 53	215	211	195	167	250	266	323	285
		3 July 53	347	256	141	133	139	144	188	113
		4 July 53	100	96	134	114	102	136	103	148
		7 July 53	19	36	17	28	25	32	115	125
		23 July 53	15	21	11	12	13	12	35	49
			696	420	498	454	529	590	764	720
			Total larvae . . *2068*				Total larvae . . *2603*			
			Mean no./sample . *129*				Mean no./inshore sample (Stns. 5 and 6) *140*			
Landsend Point	Half flood	1 July 53	108	91	79	91	99	277	145	214
		2 July 53	69	85	66	31	49	124	164	53
		3 July 53	N.D.	161	90	92	78	99	160	180
		6 July 53	9	11	15	6	17	45	75	124
		23 July 53	7	7	4	5	7	20	15	23
			193	355	254	225	250	565	559	594
			Total larvae . . *1027*				Total larvae . . *1968*			
			Mean no./sample . *68*				Mean no./inshore sample (Stns. 5 and 6) *102*			
	Half ebb	1 July 53	225	226	206	108	155	240	243	110
		3 July 53	254	96	203	N.D.	198	145	95	65
		4 July 53	111	71	67	67	46	60	30	25
		7 July 53	26	14	12	18	11	15	52	83
		23 July 53	15	1	6	15	2	5	26	20
			631	408	494	208	412	465	446	303
			Total larvae . . *1741*				Total larvae . . *1626*			
			Mean no./sample . *116*				Mean no./inshore sample (Stns. 5 and 6) *110*			

3. Current Speed and Differential Spatfall on Cross-river Transects

Differences in current speed occur over cross-river transects; the speed of flow inshore is always less than in the deeper mid-river channels. If current speed is so important, then one might expect to find denser natural oyster populations inshore, below the low tide mark and in the slow flow, than offshore in the faster flow.

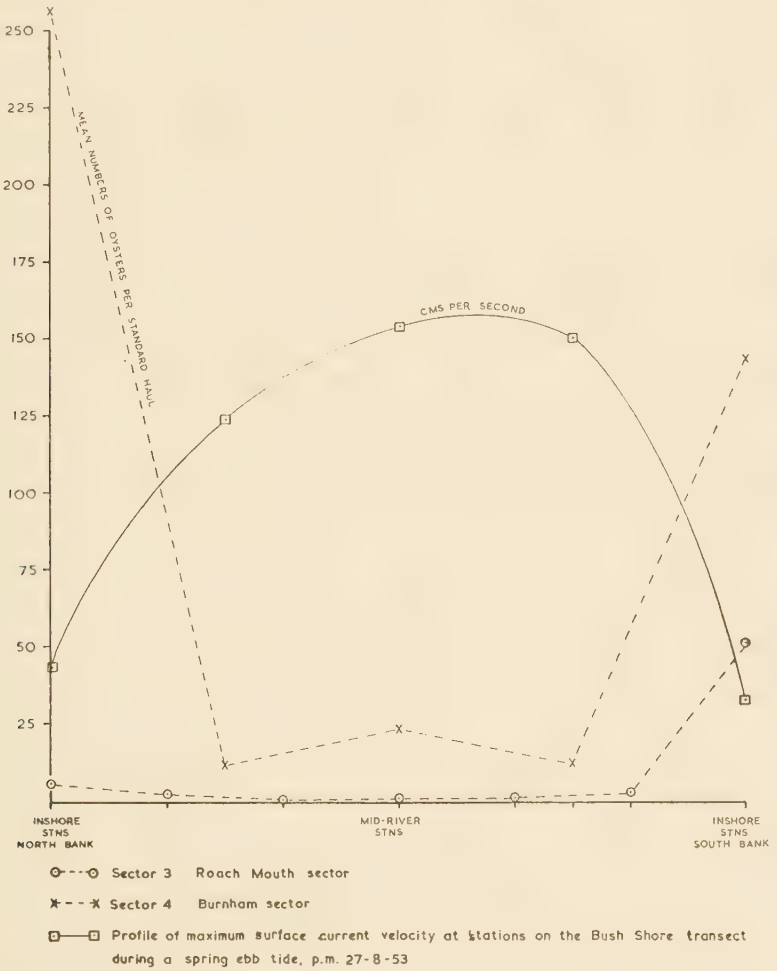


Fig. 8. *Relationship between current velocity and natural oyster abundance on cross-river transects.*

During the stock survey, dredge stations followed a systematic pattern, with lines of hauls up and down river, equal distances apart across the river. For the straight stretch of the Crouch, from Roach Mouth to Creeksea, the oyster catch per standard haul from inshore and offshore lines of stations, has been plotted against the maximum spring ebb current velocity profile for the vicinity, taken with the Plymouth flowmeter (Fig. 8). Hauls over cultivated layings were ignored. The dotted lines represent the mean oyster abundance across river in sectors 3 and 4, and the continuous line is the representative ebb current profile taken at Southward Laying in October 1953. There is an inverse relationship between oyster numbers and speed of flow in sector 3; not so marked, but still there, in sector 4.

The generalised population curve for sector 5, in the lower Creeksea region, did not fit the current velocity profile for Bush Shore. The population was high on the north bank and low on the south bank. This displacement suggested that current conditions were peculiar in this sector. Mr. Waugh of the Burnham Laboratory kindly took flowmeter readings in October 1954, during maximum ebb flow in this region. In Fig. 9, the 1951 oyster population is plotted against the later surface velocity curve. The correlation between current speed and oyster abundance is very striking. It is significant that an experimental oyster laying in this vicinity was abandoned recently, because of poor oyster growth and low productivity.

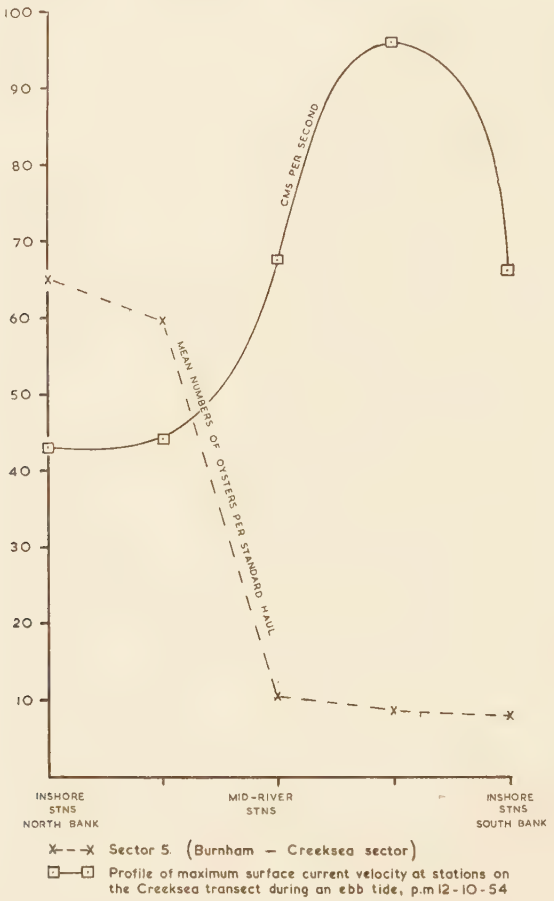


Fig. 9. *Relationship between current velocity and natural oyster abundance on cross-river transects.*

Oystermen generally lay their stocks on inshore grounds, where they are more accessible. In doing so, they also choose the most favourable position for future spat settlement, from the standpoint of current speed.

So far, it has been suggested that differences in water speed alone, by their effect on the act of larval settlement, can produce a primary pattern of spat distribution, to be reflected later in the distribution of adults. Another consideration is the possible scour effect on post-settlement survival, associated with fast flow in a turbid river.

4. Experimental Work on Scour

Whilst pump sampling in the eddy at Black Point during July 1952, I noticed the extraordinary turbidity of the water both here and in mid river. Surface samples contained

considerable amount of particulate debris. The spring tide was ebbing fast, backed by a strong westerly wind. It seemed that conditions not only of water flow, but also of sand and silt movement over the bottom, were such as to prevent settlement, and perhaps to remove larvae that had recently settled in mid river during the previous period of slack water.

A few eyed larvae were induced to settle on small pieces of oyster shell in the laboratory, and then subjected to a flow of decanted seawater with fine sand in suspension, through a simple siphon fitted with a jet of known calibre. The speed of flow was calculated by measuring the volume of water passing through the jet in a given time. The apparatus was crudely designed to test the qualitative effect of scour, and the results confirmed suspicions that the impact of fine water-borne sand, travelling at speeds below that of maximum surface flow in mid river at spring tides, was sufficient to remove two-day old spat from a plane surface. Whereas the spat stood up to a considerable clean water flow, they were unable to withstand bombardment by fine sand particles travelling at about the same speeds. Spat removal was almost immediate at the roughly-judged sand concentrations used in the experiment.

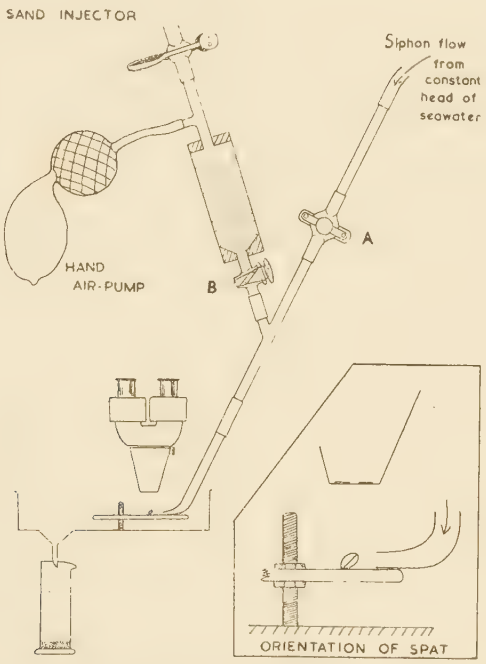


Fig. 10. *Apparatus for testing the effect of scour on oyster spat.*

An attempt was made to raise the work from a qualitative to a quantitative level during the summer of 1953, using spat from the oyster breeding tanks at Conway. The original apparatus was improved (Fig. 10), and consisted of a clamped jet of known calibre fed by a constant head of decanted seawater. The speed of flow through the jet was controlled by a screw clip A acting on a rubber junction. Fine sieved sea sand was saturated with seawater, and stored in a tubular glass injector fitted with a hand-operated air pump, which developed an even back-pressure sufficient to counteract the tendency for water to enter the injector from the main siphon, and at the same time sufficient to force sand through the control tap B, into the jet. A plastic experimental dish, provided with brass clamps, held pieces of shell carrying oyster spat of different ages.

In action, the orifice of the jet was fixed 2 mm. from a previously orientated spat (Fig. 10 inset), the adjusted flow of water and sand started, and the spat watched through a binocular microscope mounted above the jet. Water and sand ran off the shell surface into the experimental dish and drained through a filter funnel into a large measuring cylinder. At the end

of each experiment, the volume of water passed through the jet was measured directly; the sand was filtered off, dried and weighed.

Surface frictional effects on flow were minimised by siting the jet orifice close to the spat; the velocity of the current impinging on the latter was taken to be the same as the calculated velocity with which water left the jet. Steps were taken to avoid dessication by positioning the spat under water in the dish and quickly draining off before the experimental flow started. The sand used in the experiment was homogeneously fine, produced by the fractional sieving of washed sea sand. Three batches of a thousand grains gave a mean weight of 0.0165 mg. per grain, contrasting with a weight of 0.0484 mg. per grain for coarse sea sand.

Several variables have to be considered before the effect of scour on oyster spat can be rationalised. Water speed and sand concentration were the only controlled variables in this experiment. The orientation of the spat to flow and the particulate mass of the abrasive were standardised, but the age of an individual specimen could only be fixed between a minimum and a maximum.

Table 5 records fourteen spat removals in a total of 21 experiments, with variable sand concentrations at speeds above and below three knots (154 cm. per sec.), which is roughly

Table 5: *Results of scour experiments at Conway, July-August* 1953

Approx. age of spat Hours *min.*	*max.*	*Duration of expt.* *min.*	*sec.*	*Speed of water flow cm. per sec.*	*Total wt. of sand passed gm.*	*Wt. of sand passing spat per sec. mgm.*	*Effect on spat R=removal Rp=partial removal*
2	20	–	41	347·0	–	–	R
6	22	2	24	464·4	–	–	–
2	5	3	00	425·2	–	–	–
4	7	10	02	324·4	–	–	–
4	7	10	05	326·7	–	–	–
1	18	60	00	143·1	–	–	–
26	46	60	00	32·2	645·2	179·2	–
32	48	70	00	80·7	256·2	61·0	–
1	19	–	43	165·6	0·9	21·0	Rp
25	45	1	43	179·7	3·1	29·7	R
5	22	2	01	174·2	2·7	21·9	R
33	49	3	12	167·9	8·1	42·2	R
1	19	4	00	235·2	2·3	9·6	R
3	6	6	53	182·2	7·2	17·3	R
34	50	13	20	107·5	38·7	48·4	Rp
1	6	16	00	152·3	7·2	7·5	R
2	20	23	05	109·5	49·5	35·8	Rp
3	21	38	06	152·6	64·9	28·3	R
6	22	29	45	101·5	91·7	51·4	R
3	20	77	40	81·2	381·1	81·9	R
5	22	89	22	124·2	294·9	55·0	R

the maximum surface speed of ebb flow during a good spring tide in the lower reaches of the Crouch. In two cases only, did scoured spat remain fixed, both with high sand concentrations travelling at slow speeds. Young spat were, on the whole, resistant to water flow alone, withstanding speeds of 300-400 cm. per sec. On the other hand, even light injections of sand at speeds between 150 and 180 cm. per sec. were sufficient to remove spat within an arbitrary time limit of $1\frac{1}{2}$ hours. At slow speeds down to 80 cm. per sec., greater concentrations of sand were needed for removal to occur, and below 50 cm. per sec. heavy sand injections had little observable effect, once again within the arbitrary time limit.

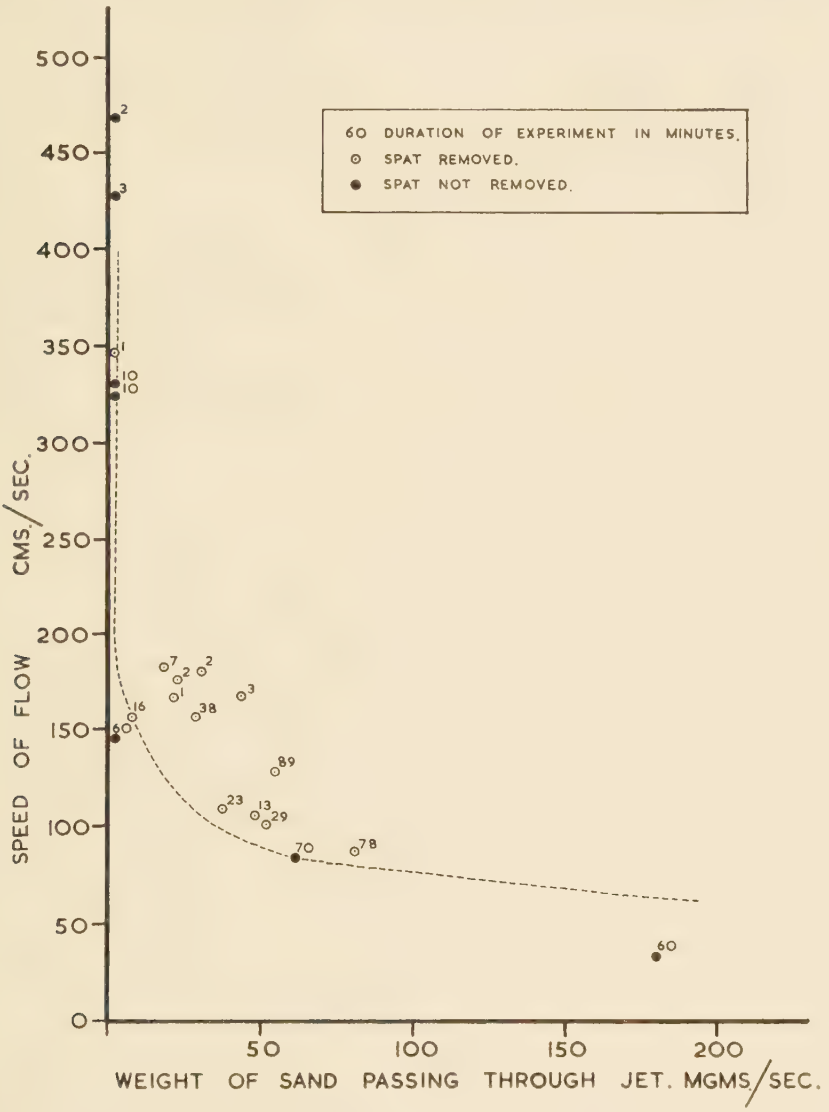


Fig. 11. *The experimental effect of variable scour on young oyster spat.*

In Fig. 11 the speed of flow is plotted against the weight of sand passing the spat per second. No extravagant claims are made for these few results; complete rationalisation of scour would involve an experimental programme designed to test separately each of the variables already mentioned. However, the graph does illustrate the way in which current velocity and sand concentration reinforce one another, to remove oyster spat, under the special conditions of the experiment.

A boundary curve has been inserted, above which current and sand combinations destroyed spat within 1½ hours, and below which they remained fixed. It must be remembered that the spat under experiment were of variable age; with increasing age, spat are likely to become more robust and more firmly attached to the substrate. The critical curve will then shift to the right. On the other hand, a shift to the left would be the expected result of bombardment by coarser sand than that used in the experiment.

If removal were due to the combined forces of a weight of water and a weight of sand exerting a shear on the spat, then the relationship between these factors would be additive and expressed graphically as a straight line. However, the critical boundary appears to be curved, suggesting a more complex relationship between the forces of water and sand. In fact, whilst a few spat were removed as a whole, other became fractured, lost their soft parts by maceration, and gradually disappeared. If maceration is the more common effect, then it is easy to understand why a light concentration of sand, injected into water flowing at a high speed, can quickly destroy a young spat, and why a heavy concentration of sand moving slowly, and lacking sufficient impetus to cut into the shell, can be withstood for a considerable length of time.

It is known that the scouring action of some African and Indian rivers can remove both soft-bodied and shell fouling from the hulls of merchant vessels (Bishop *et al.*, 1949), but to what extent scour in the Crouch influences the pattern of the yearly oyster spatfall, by its effect on post-settlement survival, must remain a subject for future field experiments. In the absence of data on the speed of bottom flow, and the nature and concentration of particulate debris in the river, the above results are merely indicative. There is however, direct evidence of scour in the fast-flowing Fairway off Burnham, where the bottom is clean, hard and liberally scattered with cultch bearing very few living organisms. Even the slipper limpet, usually found in considerable abundance offshore, cannot settle in this area.

Much work has been done on the vertical distribution of the spatfall in different localities, to determine the optimum depth for oyster settlement. Hopkins (1937) found that least *O. lurida* spat settled on the surface collectors of a series arranged at different depths. Bonnot (1936) observed no difference between the *O. lurida* spatfall in deep water and at the surface in Humboldt Bay, whereas Needler (1933) stated that the optimum of *Crassostrea virginica* occurred just below low water mark in Malpeque Bay. Seki and Tamaka (1931) arranged tile collectors between the bottom and the surface, and found the best settlement zone for *O. denselamellosa* at a distance of 0.6 metres from the bottom. A marked variability in the vertical distribution of *Crassostrea virginica* spat for different localities was discovered by Prytherch (1929, -34), in the vicinity of Milford Harbour, Connecticut. Korringa (1941) drew attention to the role that current velocity must play in determining the vertical distribution of oyster spat. In the Oosterschelde, as in the Crouch, the current velocity near the bottom is slower than in the upper layers. More spat were accordingly caught on the deeper collectors than those near the surface.

From the point of view of current speed, it is clear that the deeper, slower layers would favour high settlement, other things being equal. In a dirty river, however, the deeper layers carry more and heavier particles of sand and silt than the upper layers. Water speed and particulate content together give scour; the zone of maximum post-settlement survival in a vertical plane can therefore be expected to differ from place to place, according to geographical variation in these two factors.

The Crouch is particularly turbid, and increasingly so, according to local opinion. In 1929, the river wall at Bridgemarsh Island was breached, and the island is always inundated at high tide. Much soil is washed into the river from this breach, on the ebb tide, and contributes no doubt to scour action. The reclamation of Bridgemarsh Island would benefit both the oyster industry, by reducing turbidity and scour, and local farming interests, by a considerable addition to their arable and grazing acreage.

PART III

COMPARATIVE DREDGING EXPERIMENTS

One of the principal aims of the Ministry's oyster research programme is to step up the output of marketable oysters per man-hour for the industry as a whole. To this end, biological investigations are supplemented by efforts to develop more efficient and economical cultivation gear.

During 1951, three types of oyster dredges were in frequent use from the Ministry's vessels; the traditional hand dredge, the winch-operated 'power' dredge and the survey dredge used in the assessment of oyster stocks (Plates 1 and 2). In October of that year, three comparative dredging experiments were made with these instruments in order to gain a better understanding of their relative capabilities on different types of ground.

The first two experiments were designed to compare the catching efficiencies of the dredges on cultivated oyster layings and over heavy *Crepidula* populations. An attempt was made in the third experiment to estimate the output of oysters per man-hour for each dredge, from stocked ground.

The survey dredge and the power dredge were operated mechanically from the stern of a smack, and the hand dredge from a position amidships on the port side. All three dredges were shot and hauled together and the distance travelled per haul recorded on the pedometer of the survey dredge. The oyster catch per haul was culled out, washed, measured in terms of lb. wt. using a spring balance, and then returned to the ground. No culling out was necessary over the limpet beds, where the limpet catch was washed and weighed directly.

1. Oyster dredging on Shop Laying

20 hauls of variable length were made with the tide over Shop Laying in the R. Roach, on October 16 and 17, 1951. This ground was chosen for the experiment on account of its high state of cultivation. Relaid oysters were abundant though patchily distributed, and the bottom was firm, clean and relatively clear of pests. For purposes of this experiment, the crew of the smack were disposed as follows: 1 man on the wheel, 1 man on the winch, 2 men on the mechanised dredges, 1 man on the hand dredge.

The results given in Table 6 show that the survey dredge with its smaller blade, fished 25% more oysters by weight than the power dredge. The comparative efficiencies of all three instruments were found by adjusting the separate total catches to a standard 3 ft. length of blade. On well-worked ground, the oyster catching efficiency of the survey dredge is 80%-90% greater than that of the other two dredges. The common design of the power and the hand dredges is reflected in their similar efficiencies.

2. *Crepidula* dredging on Southward Laying

The limpet catching power of the survey dredge was very evident during the course of the oyster stock survey. Its use in reclaiming derelict ground was demonstrated over extensive *Crepidula* beds off Southward Laying in the River Crouch, the experimental technique being the same as that employed in Experiment 1.

From Table 7 it appears that the survey dredge is capable of catching twice the weight of limpets taken by the power dredge, over the same ground and distance. On adjusting the separate totals to a standard 3 ft. length of blade, the survey dredge is shown to be about 3 times as efficient as the power dredge and 5 times as efficient as the hand dredge on 'sheer' limpet beds. A vessel equipped with two survey dredges could lift one ton of limpets per hour on heavily infested ground.

Table 6: *Comparative dredging experiment* 1
Oyster dredging on Shop Laying

	Haul No.	*Time G.M.T.*	*Distance travelled to nearest yd.*	*Depth in ft.*	*Catch of oysters lb. wt.*		
					Survey dredge	*Power dredge*	*Hand dredge*
16 Oct. 51	1	0905	33	8	45½	47	20¼
	2	0930	40	13	28	24	14
	3	0945	43	19	50½	30	4½
	4	1010	36	16	33½	35½	13¾
	5	1031	37	17	36¼	19½	18¼
	6	1050	31	16	53	39	15¼
	7	1240	42	23	15¾	15¾	11½
	8	1305	19	24	16¼	17¾	12¾
	9	1320	17	26	18	32	10¼
	10	1332	18	26	32½	33½	20½
	11	1345	47	19	64¼	43¾	22¾
	12	1415	42	16	46	37	25
17 Oct. 51	13	1024	42	15	31¾	22¾	6½
	14	1035	48	16	30¾	31½	11½
	15	1058	40	17	21½	18½	8
	16	1235	53	23	32½	28¾	15
	17	1245	27	23	26¼	8½	9¾
	18	1310	53	19	48¼	33¼	11½
	19	1324	45	23	35	23¾	13¼
	20	1335	35	26	32	18	8½
Totals	20		748		697¾	559¾	272¾
Adjusted totals per 3 ft. width of blade					697¾	373⅛	385
Comparative efficiencies					1·87	1·00	1·03

Table 7: *Comparative dredging experiment* 2
Crepidula *dredging on Southward Laying*

	Haul No.	*Time G.M.T.*	*Distance travelled to nearest yd.*	*Depth in ft.*	*Catch of limpets lb. wt.*		
					Survey dredge	*Power dredge*	*Hand dredge*
18 Oct. 51	21	0915	42	26	178½	92¼	20¼
	22	0934	16	26	182¾	110½	33¾
	23	0945	14	23	259¾	89¾	9½
	24	0955	37	26	140¼	71	18½
	25	1005	45	26	224	106½	54
	26	1035	36	26	225¾	81¼	48
	27	1324	23	38	213¼	81¾	8¾
	28	1330	29	38	120	51½	15½
	29	1345	30	34	60½	33½	5
	30	1400	49	39	163½	84½	22¾
Totals	10		321		1768¼	802½	237¼
Adjusted totals per 3 ft. width of blade					1768¼	535	335
Comparative efficiencies					3·30	1·00	0·63

3. Output of oysters per man-hour on Shop-Laying and Paglesham Reach

The survey dredge has a low degree of selectivity. Even on the cleanest of the Ministry's layings a good proportion of the material brought up from the bottom consisted of various pests, old and new cultch and other debris. Much time is normally spent, between hauls, separating oysters from the rest of the catch. An experiment was carried out in the River Roach to assess the effect of this time loss on the output of oysters per man-hour, using the same dredges and general technique as in the previous experiments. In addition, the total time taken to shoot, tow, haul and cull the catch was recorded for each dredge. Four men worked the two mechanised dredges and winch, whilst an experienced dredgeman operated the hand dredge. One man was at the helm. To even out differences in culling ability, the men on the survey and power dredges were constantly switched around.

The survey dredge once again fished 25% more oysters by weight than the power dredge and three times that of the hand dredge over the same distance (Table 8). The comparative efficiencies are similar to those derived from Expt. 1. It can be safely said that the survey dredge is over 80% more efficient in oyster catching ability than the other two dredges on this type of ground, and is therefore better suited for use in quantitative investigations.

Table 9 gives the calculated output of oysters per man-hour per dredge in terms of lb. wt., and shows that this output bears an inverse relationship to the efficiency. The mobility of the hand dredge more than compensates for its low catching ability, whereas the greater fishing power of the mechanised dredges is countered by the increased time taken to cull out the catch.

Table 8: *Comparative dredging experiment* 3

Oysters on Paglesham Reach (*hauls* 31-37) *Oysters on Shop Laying* (*hauls* 37-40)

	Haul No.	Time G.M.T.	Distance travelled to nearest yd.	Depth in ft.	Survey dredge		Power dredge		Hand dredge	
					Time taken min. sec.	Oyster catch lb. wt.	Time taken min. sec.	Oyster catch lb. wt.	Time taken min. sec.	Oyster catch lb. wt.
5 Nov. 51	31	1000	52	16	18·55	107¾	8·05	42	7·03	6¾
	32	1020	50	15	13·20	38½	10·35	43¼	5·02	13
	33	1110	27	16	9·55	51¼	10·54	56½	5·05	16¾
	34	1125	10	16	15·15	50	9·45	40¾	5·30	16¼
	35	1146	35	16	13·20	71¾	9·20	45¾	6·05	29¾
	36	1327	34	20	12·36	30	12·38	49¼	6·36	20½
	37	1345	48	20	11·58	10	11·33	29½	3·15	10½
	38	1407	26	8	6·05	9¼	4·33	19	4·30	18½
	39	1435	52	13	14·03	56¼	9·03	38¼	6·45	19
	40	1451	56	11	14·51	79¾	9·46	47¾	6·25	22¼
Totals	10		390		130·18	504½	96·12	412	56·16	173¼
Adjusted totals per 3 *ft. width of blade* . . .						504½		274⅔		244$\frac{9}{17}$
Comparative efficiencies						1·84		1·00		0·89

Table 9: *Output of oysters/dredge/man-hour Derived from Table* 8

Dredge type	No. of men employed on dredge	Oyster catch lb. wt.	Time taken min. sec.	Output oysters per man-hour	Ratios of output per man-hour
Survey	2	504½	130·18	116	1·00
Power	2	412	96·12	129	1·11
Hand	1	173¼	56·16	185	1·59

From the time taken to shoot, tow, haul and cull the catch for each type of dredge (Table 8), it is possible to estimate the number of hauls per hour made by a five man vessel equipped with either two survey dredges or two power dredges or four hand dredges, during routine cultivation. These are four, six and nine respectively, an estimate confirmed by experienced dredgermen. Table 10 compares the theoretical output of oysters per hour for a vessel equipped with the alternatives suggested above, and completing the appropriate number of hauls an hour over an area such as Paglesham Reach or Shop Laying, assuming

Table 10: *Theoretical output of oysters for a 5-man vessel per hour over Shop Laying and Paglesham Reach*

Derived from Table 6. 16-17 Nov. 51—Total of 20 hauls

Number and type of dredge	*Estimated no. hauls/hr.*	*Estimated total oyster catch lb. wt.*	*Calculated oyster catch per hr. lb. wt.*	*Ratios of hourly output*
2 *Survey*	4	1395	279	1·00
2 *Power*	6	1119	335	1·20
4 *Hand*	9	1091	491	1·76

Derived from Table 8. 5 Nov. 51—Total of 10 hauls

Number and type of dredge	*Estimated no. hauls/hr.*	*Estimated total oyster catch lb. wt.*	*Calculated oyster catch per hour lb. wt.*	*Ratios of hourly output*
2 *Survey*	4	1009	404	1·00
2 *Power*	6	824	494	1·22
4 *Hand*	9	693	624	1·54

a constant oyster population. The data collected on 16-17 Oct. 51 and on 5 Nov. 51 are construed separately. There can be little doubt of the output supremacy of the hand dredge under these experimental conditions. Its usefulness in long term cultivation will be considered in the discussion below.

4. Discussion

These comparative dredging experiments clearly demonstrate the effect of design on dredge efficiency. The action of the survey dredge can be likened to a plane or scoop, as opposed to the scraping action of the power and hand dredges. The sledge design undoubtedly gives better clearing of the ground covered, and is therefore recommended for further development. Its performance in Experiment 2, over 'sheer' limpets, was quite remarkable, and there is no reason to suppose that the effect would be any less striking over 'sheer' oysters. Experiment 3 suggests that the economic advantage of this extra efficiency is lost when used on oyster beds that are not thoroughly clean, or where stocks are not arranged in an orderly manner according to age or size. This loss could be diminished by the use of fast winches and the development of a speedy culling technique.

Tables 8-10 draw attention to the usefulness of the hand dredge in lifting oysters from mixed ground, but in deciding which dredge is the best proposition for general use, it is necessary to consider the established principles of oyster cultivation. Dredging is a continuous process, as important from the point of view of cleaning ground and sorting stocks, as it is for lifting marketable oysters for sale. As a ground becomes more homogeneous, so the output of oysters per man-hour with any dredge must increase, less and less time being spent in culling the catch. The mechanised dredges, with their greater catching power, will bring a derelict ground to a high state of cultivation in less time than an equivalent number of hand dredges, and are more likely to maintain it in that condition. The hand dredge has the advantage, however, in certain restricted circumstances: the rapid collection of marketable oysters from heterogeneous ground during the selling season, and possibly for use in lifting brood oysters from the uncultivated breeding grounds of the Crouch.

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SUMMARY

In the autumn of 1951, a new type of dredge, working on the sledge principle, was designed for surveying the oyster stock of the Rivers Crouch and Roach, Essex. After trials and calibration, 700 hauls were made over an area of river bed some $13\frac{1}{2}$ million square yards in extent, and a reasonable estimate reached of the total oyster stock and its age composition.

The River Crouch had a population of $18\frac{1}{2}$ million native oysters, 15 million of which were one-year-old brood oysters from the 1950 spatfall, the remaining $3\frac{1}{2}$ million being spawning stock. The River Roach contained $7\frac{1}{4}$ million oysters; only $2\frac{1}{2}$ million were one-year-old brood.

The Crouch is evidently a better spatting river than the Roach, due, in part, to the heavy spatfall under inshore eddies. There are four such eddies in the Crouch, and only one in the Roach.

Planktonic larvae do not accumulate in eddies, but flowmeter readings suggest that the water flow inside is below the critical speed for the act of larval settlement, for a longer time per tidal cycle, than the flow outside. Similarly on cross-river transects; naturally set oysters were more abundant inshore, in the slow flow, than offshore, in the fast flow.

The Crouch is a turbid river; the effect of current velocity on the initial pattern of oyster settlement, might well be reinforced by the secondary effect of scour on post-settlement survival. Newly settled oyster spat were subjected, in the laboratory, to a variable flow of seawater and homogeneously fine sand through a jet. At water speeds and sand concentrations comparable with those in the Crouch, spat were removed, usually by maceration, from shell surfaces.

Turbidity and associated scour must play an important part in restricting the oyster spatfall from year to year; it is therefore suggested that efforts be made to reclaim land normally inundated at high tide, and thus bring benefit to both farming and oyster industries.

A series of comparative dredging experiments showed that the sledge type survey dredge is ideal for clearing and reclaiming infested oyster grounds, but that the dredges of orthodox design, with their greater mobility and selectivity, are more economical for lifting marketable oysters on mixed ground.

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